Autonomous Operation of a Coordinated Underwater Glider Fleet

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LONG-TERM GOALS

Webb Research Corporation (WRC) and Rutgers University (RU) plan to provide an important advance in regional-scale coastal ocean observation programs by operating a coordinated fleet of glider AUVs in an intelligent adaptive network. Slocum autonomous underwater vehicle Gliders (AUVGs) are uniquely mobile network components capable of moving to specific locations and depths, occupying controlled spatial and temporal grids, and will conduct their third annual test this July during the final ONR-sponsored Coastal Predictive Skill Experiment (CPSE) at Rutgers' local-scale (30 km x 30 km) Long-term Ecosystem Observatory (LEO). Over the following year, a fleet of second-generation Slocum Gliders will be constructed by WRC and utilized at RU for operation within the developing regional-scale (300 km x 300 km) New Jersey Shelf Observing System (NJSOS). The challenge ahead is to determine how best to operate a coordinated fleet of Gliders beneath the spatially-extensive regional remote sensing systems given cues from multiple real-time datasets and model forecasts. This requires the development and testing of (a) new compact and low-power physical, chemical, and bio-optical sensors for the Gliders, (b) ocean feature detection software to provide the cues and response on an individual and fleet scale, (c) new bi-directional robust communications systems, and (d) a networked autonomous Glider command/control center.

Fig. 1. SLOCUM Electric AUVG Post-deployment, LEO-15, NJ

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14. ABSTRACT
Webb Research Corporation (WRC) and Rutgers University (RU) plan to provide an important advance in regional-scale coastal ocean observation programs by operating a coordinated fleet of glider AUVs in an intelligent adaptive network. Slocum autonomous underwater vehicle Gliders (AUVGs) are uniquely mobile network components capable of moving to specific locations and depths, occupying controlled spatial and temporal grids, and will conduct their third annual test this July during the final ONR-sponsored Coastal Predictive Skill Experiment (CPSE) at Rutgers’ local-scale (30 km x 30 km) Long-term Ecosystem Observatory (LEO). Over the following year, a fleet of second-generation Slocum Gliders will be constructed by WRC and utilized at RU for operation within the developing regional-scale (300 km x 300 km) New Jersey Shelf Observing System (NJSOS). The challenge ahead is to determine how best to operate a coordinated fleet of Gliders beneath the spatially-extensive regional remote sensing systems given cues from multiple real-time datasets and model forecasts.

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OBJECTIVES

Review available sensors, develop expanded glider sensor capabilities of appropriate low-drag, low-power characteristics.

Create a removable hull section/cargo bay for sensor payload, to facilitate ease of installation, maintenance, exchange, and calibration.

Examine methodology for data integration/modeling that cross benefit remote sensor systems identifying products deemed useful by Navy and science needs.

Improve data and communication into a central network. Outline a command/control center where prioritized mailboxes exist to invoke levels of glider behavior. An event triggered by a remote sensor package or another glider can cause a new adaptive set of instructions to be downloaded to a glider.

Develop adaptive sampling protocol for autonomous glider ocean-feature recognition and response. Prepare tools that aid in the operation of a fleet of vehicles, such as dynamic mapping, event data display, email and pager alerts to enable a person to keep track of abort situations.

Investigation to enhance RF communications. The ultimate goal is to integrate a global bi-directional satellite communications system, while retaining the RF modem system for high-speed local communications.

APPROACH

The core team consists of Clayton Jones a project engineer at WRC, Tom Campbell a software engineer residing at WRC (Dinkum Software), and Drs. Scott Glenn and Oscar Schofield of Rutgers University (Institute of Marine and Coastal Sciences).

A cooperative effort and technology transfer between Webb Research Corporation (WRC) and Rutgers is a well-balanced and timely exploitation of the glider capability. WRC is strong in the fields of innovative hardware design, compact sensor packaging, low-power operation, radio frequency and satellite communication systems. Rutgers has great expertise in command control centers, adaptive sampling schemes, and creating nowcasts and forecasts from a diverse set of input data and rendering practical science.

WORK COMPLETED

Rutgers has chosen to have a HOBI Labs Hydroscat-2 backscatter and fluorescence sensor to be integrated into the modular payload bay while retaining the present low profile ctd. Drawings have been obtained from HOBI Labs showing essential sensor dimensions and a design is underway to create a hull section with the optical head of the sensor exposed on the bottom of the glider. Rutgers is looking at other sensor packages that may be integrated at a later date such as red tide detectors.

A modular mid-section payload bay for the glider has been designed and implemented, for this and other projects, with success at the July 2001 LEO-15 trials. The present payload bay is 8 3/8" diameter and 12" long with a nominal capacity of 3 to 4 kg. Designed to be easily removed and replaced for calibration needs or sensor type changes this gives great ease and flexibility to the user. To

complement this section, an interface has been created to allow a payload or science bay computer to be installed which can control the sensor packages and collect and store data. Any control system is applicable i.e. embedded processors, PC104, etc. Combined with Glider Simulation software this division of architecture allows users to develop sensor system packages on their own bench without the need for glider hardware or worry of jeopardizing vehicle functionality. Defined protocol allows the payload/science computer to request mission changes such as new waypoint or sampling scheme, direct world communication access, or knowledge of any of the vehicles senor variable thus creating a truly adaptive vehicle.

Effort has been made to improve data and communication into a central network called Glider Mission Control. A command/control center has been outlined where prioritized mailboxes exist to invoke levels of glider behavior, cause outside world action, create products, and allow access to data sets. Outlined is a single machine to handle serial input from a number of vehicles. All gliders will report in and out of this system, which will be the gateway for automated adaptive sampling and automated data retrieval. Presently by RF 900 Mhz modem, and later dialup, the vehicles initiate the communication. String text recognition takes place to identify the status of the vehicle i.e. normal mission segment reporting, end of mission, abort mission, hardware failure, etc. Based on the text string GMC then branches to the appropriate mailbox to check for any action. Users, both human and automated, can place a set of instructions into a mailbox that is associated with a particular text string. For instance, if there exists an abort string the user may enter an email address or pager number and cause a message to be sent. These actions are chainable so that one can change the vehicle's destination by associating a new waypoint with the "normal mission segment string" mailbox along with segment data extraction, and email notification the next time the glider reports in. Automation can be achieved in the sense that an event measured by another science system; satellite imagery, ship data, modeling information, or another glider can cause a new adaptive set of instructions to be placed in an appropriate mailbox to be subsequently downloaded to a glider. Such as, download new mission dynamics at the next glider surfacing to change the onboard sensor-sampling scheme. The goal is to create a flexible, user friendly, robust command/control system that can be accessed remotely. In addition, the system will have the capability to make data sets available so as to create products for science and navy needs and items like an updated vehicle location map to aid in human or automated decision making when commanding the fleet. A Bayesian Belief Network/ Influence Diagram is used to implement a decision network. A utility value is assigned to each of the outcomes; whichever action maximizes the utility is implemented. The decision network is dynamic in nature, as new sources of information are known the network evolves to incorporate it in its decision. Implementation of this software is done in Java 1.2.

An important aspect of this agent is to provide graphical products for the data analysis. Rutgers has been massaging the data set created by the glider from trials in 1999, 2000, and 2001. Scripts have been written to develop temperature, salinity, density, and depth averaged current products that are integrated into models. This hands-on experience of real world data has prompted suggestions for better measurement techniques and sampling schemes to be incorporated in the gliders. Plotting in order to create useful products is done using NOAA's Java based Scientific Graphics Toolkit (SGT).

Paths have been developed to acquire Iridium service, support, and hardware to enable integration, testing, and antenna design. An Iridium phone has been successfully dismantled to allow circuit board style integration. A baseline study of the phone's performance, both as provided in a case and dismantled, with a standard quad-helix antenna has been completed. Also, Iridium phone to Iridium

phone data transfers have been made. Initial antenna design with a pressure rating to 10,000 PSI has taken place.

REUSLTS

Glider Mission Control center and related products are a work in progress. Data infusion into models and graphical representation are valuable tools to allow human interface and understanding of vehicle performance and data analysis. One such example is that although the Gliders are not equipped with a current meter sensor, their observed drift between surface intervals can be used to infer depth-averaged velocities and compare well to CODAR and ADCP measurements. Glider-derived vertically averaged velocity estimates are based on the differences between the actual GPS position and the expected position based on dead reckoning every time the Glider surfaces. Whenever the Glider was within 2 km of a LEO ADCP during the July deployment, the Glider depth time series was used to average together the corresponding ADCP velocities (Fig. 2).

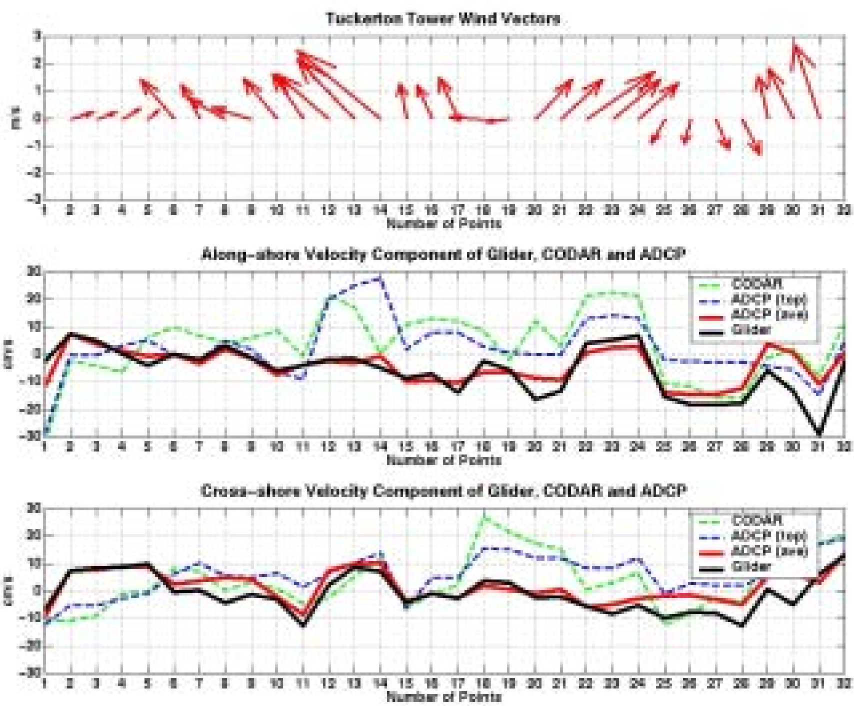

Fig. 2. Comparison of Glider, ADCP, and CODAR-derived along-shore (middle) and cross-shore (bottom) currents and their relation to the local wind vectors (top) during the July 2000 deployment.

Reducing and Iridium phone to its bare cards has allowed for better volume integration in a glider. As with many in the community, our desire is to purchase an OEM Iridium board set that is sensitive to a typical autonomous vehicle's power, weight, and size considerations. Iridium has acknowledged this desire and is having an OEM board set manufactured. Delivery is slated to be in 6 weeks. A baseline study of the phone's performance, both as provided in a handheld case and dismantled, with a standard quad-helix antenna has been completed. Dismantling the phone does not seem to have any significant results on operability. A test environment with two phones has been created and tests have begun sending 1K data packets from one Iridium phone directly to another Iridium phone, which reduces the

airtime costs and eliminates the use of landlines from Tempe, AZ. After characterizing these operations through a standard bifilar antenna, different form factors will be tested. For form factor reasons, such as drag and repeated 10,000 PSI pressurization, further research is going into what degradation will other types of antennas incur, and are they functional? Having a spatially insensitive bi-directional communication path is viewed as essential to operating long range multi-vehicle operations.

IMPACT/APPLICATIONS

Real-time characterization of rapidly evolving 3-D coastal environments is central to the objectives of numerous academic, government, civilian and industrial users. Navy Rapid Environmental Assessment applications in denied areas, Coast Guard search and rescue, oil exploration, production and spill response, and commercial fishing will benefit from new observatory technologies. Slocum Gliders are a key backbone component of regional-scale coastal ocean observatories. The NJSOS system already has 3 Slocum Gliders available (2 - ONR, 1- New Jersey) with another 4 requested (2 - NSF, 2- New Jersey). Developing the ability to autonomously operate the Gliders as a coordinated fleet over the next 2-3 years is a necessary step to keep pace with ongoing development projects for other system components. Ease and automation of operations with regard to needed sensor data sets will leverage commercial viability. In addition, practical products such as satellite ground truthing, and third dimension data analysis will demonstrate functionality of a fleet of gliders. Several Universities and groups are interested and have placed orders for Slocums as littoral survey vehicles that report environmental information from such sensors as CTDs, a proposed red tide detector, optical sensors (fluorometer, PAR, transmissometer), and hydrophones.

TRANSITIONS

Creating tools to support fleets of underwater vehicles will strengthen the usefulness of such systems and allow expansion of our knowledge base of the environment. The information learned about Iridium integration is being shared with other groups and universities.

RELATED PROJECTS

Woods Hole Oceanographic Institution (WHOI) -- WRC will deliver 3 Slocum gliders to Dr. David Fratantoni which will be used as a coordinated fleet to provide nearly-continuous hydrographic and optical measurements over a one year period at the Martha’s Vineyard Coastal Observatory (MVCO).

WHOI -- WRC will deliver 2 Slocum-Thermal gliders to Dr. David Fratantoni to be used as an autonomous observing network near the long-term Bermuda Atlantic Hydrographic Time Series station.

Rutgers -- WRC has been involved in the LEO-15 project during July 1999, 2000, and 2001. We expect to continue collaboration with Dr. Scott Glenn and colleagues from Rutgers University in this multi-institution National Ocean Partnership Program (NOPP). WRC will deliver 3 Slocum gliders to Rutgers under a DURIP, and there is a NSF proposal for 4 additional Slocum gliders.

DREA -- WRC will deliver 2 Slocum gliders with integrated Telesonar modems to the Canadian defense lab for trials in January 2001.

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